Recent Progress of the Liege Intranuclear Cascade Model

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The Liege Intranuclear cascade model has recently evolved to a numerical code INCL4, which, without any parameter tuning, is able to give good results for an impressive set of data concerning spallation reactions in the 100 MeV to 2 GeV range of incident energies[1]. These data include total reaction cross-sections, neutron and proton double differential cross-sections, particle multiplicities, residue mass and charge spectra, isotopic distributions and residue recoil energy distributions, for proton-induced as well as deuteron-induced reactions. The success of this version of the Liege INC code comes mainly from the introduction of a diffuse surface, from an improved treatment of the Pauli principle and from a self-consistent determination of the stopping time, i.e. the time at which the cascade is stopped and the evaporation code is started. This feature seems to free the model from the introduction of a so-called pre-equilibrium module.

Here, we report on new advances in the development of the Liege INC model. They cover:
(1) An investigation of the behaviour of the model at low energy. It will be shown that the model gives reasonable results for neutron and proton double differential cross-sections down to 40-50 MeV of incident energy, i.e. much lower that the theoretical limit of validity, provided the handling of the Pauli principle is further improved, especially by a refined evaluation of the phase space occupancy.
(2) The introduction of a nuclear mean field that depends upon the isospin and the energy of the nucleons, as suggested by the optical model phenomenology[2]. It will be shown that these modifications decrease the multiplicity of the neutrons emitted in the cascade stage and increases the excitation energy left in the remnant at the end of this stage. This helps to improve the predictions of the model for the residue mass spectrum in the fragmentation domain.
(3) An improvement of the pion production. A potential for the pions is introduced, as well as an improvement of their re-interaction accounting for medium corrections. Results will be shown and discussed.
(4) Predictions of correlations. Two types of correlations are investigated in view of the forthcoming PISA and SPALADIN experiments at Julich and GSI, respectively. They relate to angular correlations of fast particles and to correlations of the multiplicity of fast protons and neutrons (and of the energy carried by these particles) with the mass of the residue. This type of observables is expected to constrain INC+evaporation models quite stongly, as they are sensitive to the way energy is released in the two stages of the reaction process. Results will be discussed.

[1] A. Boudard, J. Cugnon, S. Leray and C. Volant, Phys. Rev. C66 (2002)044605.
[2] E. Gadioli and P. Hodgson, Pre-equilibrium Nuclear Reactions, Clarendon, Oxford, 1992.

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